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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF ENTRANCE WIDTH-TO-HEIGHT RATIO ON THE PERFORMANCE OF AN AUXILIARY SCOOP-TYPE INLET AT MACH NUMBERS FROM 0 TO 1.3

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

As a part of an investigation of variable-area auxiliary inlets intended to provide for the variation of engine air requirements with speed and altitude, three auxiliary scoop inlets were tested in combination with a nose inlet at Mach numbers from 0 to 1.3 at zero angle of attack. These auxiliary inlets had inlet areas equal to 12 percent of the main-inlet area. Two values of scoop width-to-height ratio were investigated for inlets with sharp lips, and a third model was tested with rounded lips. Comparison with the results of a preliminary investigation indicates that gains of about 7 percent in the effective-thrust ratio were attained at a Mach number of 1.1 by reducing the scoop width-to-height ratio from 13.4 to 2.4.

INTRODUCTION

Some method of providing turbojet engines with the varying quantities of air they require over a range of flight conditions has been found to be necessary in order to maintain a high level of thrust (refs. 1 and 2). One simple method of satisfying these varying requirements has been investigated and reported in reference 2; in this preliminary investigation, a variable-area scoop-type auxiliary inlet of large width-to-height ratio was tested. Substantial gains in effective thrust, relative to a fixed-area inlet, were calculated to be attainable with the preliminary design over a large portion of the speed range from 0.77 to 1.30 Mach number. The preliminary tests indicated that the performance of the auxiliary scoop was probably limited by the body boundary layer and a large flow turning angle at the outer lip. It was suggested in reference 2 that further gains in thrust might be attained by reducing the width-to-height

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ratio of the auxiliary scoop and more nearly alining the lips with the local flow direction. It is the purpose of the present investigation to establish the importance of the width-to-height ratio and the lip alinement and to indicate the gains possible with these design refinements.

NOTATION

A	cross-sectional duct area, sq ft
C_F	effective-thrust ratio, $\dfrac{F_i - D}{F_s}$, dimensionless
d	distance of survey-rake tube from bottom of main duct, in.
D	drag, $(p_w - p_o)\left[(A_1 + A_{1a}) - A_{o_T}\right]$, lb
F_i	internal thrust, lb (see ref. 1)
F_s	internal thrust based on isentropic total-pressure recovery, lb
H	total pressure, lb/sq ft, absolute
M	Mach number, dimensionless
m	mass-flow rate, ρVA, slugs/sec
m_{T_o}	mass-flow rate based on total inlet area, $\rho_o V_o A_T$, slugs/sec
m_{T_*}	mass-flow rate through total inlet area at uniform sonic velocity with free-stream total pressure, $\rho_* V_* A_T$, slugs/sec
p	static pressure, lb/sq ft, absolute
V	velocity, ft/sec
w	auxiliary-inlet-flap width, in.
x	station downstream of main-duct entrance, in.
ρ	mass density, slugs/cu ft

Subscripts

a	auxiliary
T	total
w	conditions just downstream of normal shock wave
o	free stream
1	main-inlet-entrance station
1a	auxiliary-inlet entrance
2	outlet station of auxiliary duct
3	diffuser-exit and survey-rake station
4	upstream mass-flow measurement station
5	downstream mass-flow-measurement station
*	sonic conditions

APPARATUS AND TESTS

The tests were conducted in the Ames 2- by 2-foot transonic wind tunnel. A description of the equipment, test methods, and accuracy is presented in reference 2. The Mach numbers of the tests were 0, 0.20, 0.77, 0.95, 1.13, and 1.30; at the highest Mach number the Reynolds number based on the main-inlet diameter was approximately 1/2 million.

Three auxiliary-inlet configurations were tested with a conventional normal-shock inlet (see fig. 1). Two of the inlets had a frontal aspect ratio (width-to-height ratio) of 2.4, while the aspect ratio of the third inlet was 13.4. The lower-aspect-ratio inlets differed in two respects: One had a constant internal cross-sectional area for a distance of about one duct height downstream of the sharp-lip entrance; the other was made from the first by cutting off the external duct walls of the constant-area section and rounding the resultant lips to a semicircle approximately 0.027 inch in diameter. Within the Mach number range of this investigation, the flow conditions at higher speeds were considered more critical than those at lower speeds; for this reason, the auxiliary-inlet area used in the present investigation was set to equal 12 percent of the main-inlet area, and no other values were investigated.

It should be pointed out that in this investigation, the included wedge angle of the lips of the auxiliary inlets was only 4° and that the auxiliary duct walls were alined with the local flow direction; as a result, the flow turning angle at the inlet station was reduced roughly 15° from that of reference 2. The high-aspect-ratio inlet had the same frontal dimensions as the inlet of the preliminary investigation, but the duct was approximately 35 percent shorter. The low-aspect-ratio inlet having sharp lips and a constant-area section had the same duct length as the inlet of the preliminary investigation. All three auxiliary ducts had constant rates of area increase with length in the diverging sections.

The quantities measured during the tests were the static pressures at stations 0, 3, 4, and 5 and the total pressures at stations 0 and 3. Since the total-pressure rake at station 3 did not provide a complete survey of the flow field, its readings were used only for determining the total-pressure profiles in the vertical midplane at that station. The total-pressure ratios H_4/H_0 presented in this report were calculated by the use of the continuity of mass relation in conjunction with the static pressures and flow areas at stations 4 and 5.

RESULTS AND DISCUSSION

The variation of the total-pressure ratio at station 4 with mass-flow ratio[1] for the inlets tested are presented in figure 2, together with data of reference 2 for comparison. Total-pressure profiles in the vertical midplane of the duct at station 3 for the low-aspect-ratio inlet with sharp lips at Mach numbers of 0.77, 0.95, and 1.13 are given in figure 3; similar data for a high-aspect-ratio inlet are given in reference 2.

The effect of reducing the frontal aspect ratio is to increase the total-pressure recovery at the higher mass-flow ratios (see fig. 2). This increase was maintained over the range of test Mach numbers. At Mach numbers below 1.3 the recovery with the auxiliary inlet approached the recovery of the main inlet. However, at $M_0 = 1.3$ the recovery was 3 to 5 percent lower (see fig. 2(f)). At mass-flow ratios less than about 0.8 and at Mach numbers of 0.95 and above, the total-pressure

[1]The mass-flow ratios m_T/m_{T_*} and m_T/m_{T_0}, for subsonic and supersonic speeds, respectively, have been employed to facilitate comparisons of the air-induction-system characteristics at various auxiliary-inlet openings. The ratio m_T/m_{T_*} is the total actual mass flow divided by the total mass flow when the air openings are choked; the ratio m_T/m_{T_0} is the total actual mass flow divided by the mass which would flow in the free stream through an area equal to the total inlet area.

recovery for the high-aspect-ratio inlet was slightly higher than that of the low-aspect-ratio inlet. This fact is contrary to expectations, and the reason for it is not understood.

The effects of alining the outer lip with the local flow direction and of shortening the auxiliary diffuser are shown by the total-pressure recovery at $M_o = 1.3$, plotted in figure 2(f) for the 13.4-aspect-ratio inlets. In the high-mass-flow-ratio range, the total-pressure recovery of the inlet used in the present investigation is 2 to 4 percent higher than that of the preliminary model. At Mach numbers less than 1.3, the difference in recoveries was negligible.

The effects of rounding the lips of the auxiliary inlet and eliminating the constant-area section were small at Mach numbers of 0 and 1.3 (see figs. 2(a) and 2(f)) and moderate at 0.2 (fig. 2(b)). At the other test Mach numbers the effects were negligible and are not shown in the figures for that reason.

It is reasonable to expect the foregoing effects to apply qualitatively in the case of duct systems in which other inlet-area ratios are used. Analysis of the data suggests that further improvements in performance of the auxiliary inlets tested may be expected mainly through a reduction of boundary-layer effects. The two obvious methods appear to be: (1) further reduction of the frontal aspect ratio, and (2) control or removal of the boundary layer. The first method appears to be impractical because of the large slope of the outer auxiliary-duct wall. Possible improvements with the use of the second method, that is, boundary-layer removal, can be estimated from the data published in reference 3.

The effect of the improvements in pressure recovery and mass-flow ratio relative to the results reported in reference 2 are shown in figure 4 in terms of an effective-thrust ratio (C_F) for an altitude of 35,000 feet. The values of the effective-thrust ratio were obtained by the methods of reference 1 and by assuming the turbojet engine of the propulsion system to have air-flow and thrust characteristics similar to those of the J-57-P1 engine when operating at normal rated power. The uppermost curve in figure 4 is that which would be obtained if the main-inlet area were continuously variable with Mach number as required for the optimum performance. The lowest line (at $M_o = 0.8$) in figure 4 indicates the values of C_F that would be obtained without an auxiliary inlet with the main-inlet area fixed at the design value for $M_o = 1.3$ and an altitude of 35,000 feet. The remaining lines show the effective-thrust ratios attainable with the auxiliary inlets tested when the total inlet area is 112 percent of the design value. The decreases in C_F below those for best operation at the higher Mach numbers are due to air spillage, and the decreases at lower Mach numbers are due to insufficient inlet area. A variable auxiliary opening which would be closed at a Mach number of 1.3, open 12 percent at a Mach number of 1.1, and 24 percent open at a Mach number of 0.9 (ref. 2) would have the best possible

effective thrust at the maximum Mach number and would be within 2 percent of the optimum at other high-speed flight conditions. Furthermore, still larger auxiliary-inlet openings can provide improved low-speed performance.

CONCLUSIONS

Scoop-type auxiliary inlets with inlet areas equal to 12 percent of the main-inlet area were tested in combination with a conventional normal-shock inlet in the range of Mach numbers from 0 to 1.3. The following conclusions were drawn from the test data of this and of the preliminary investigation and from an evaluation of the results in terms of an effective-thrust ratio:

1. The effective-thrust ratio attainable at a Mach number of 1.1 with the auxiliary inlet having a width-to-height ratio of 2.4 was within 2 percent of that possible with the main inlet alone, and was about 7 percent greater than that attained with the auxiliary inlet having a width-to-height ratio of 13.4.

2. The effect of altering the outer lip angle to approach more nearly the local flow direction was small at Mach numbers below 1.3. At Mach number 1.3 a gain in total-pressure ratio of from 2 to 4 percent was observed.

3. The effects on total-pressure recovery of a moderate amount of lip roundness and of a constant-area section in the auxiliary inlet were small at all Mach numbers.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., May 28, 1953

REFERENCES

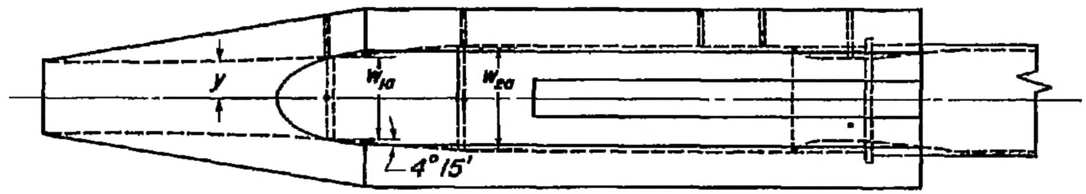
1. Brajnikoff, George B.: Method and Graphs for the Evaluation of Air-Induction Systems. NACA TN 2697, 1952.

2. Scherrer, Richard, Stroud, John F., and Swift, John T.: Preliminary Investigation of a Variable-Area Auxiliary Air-Intake System at Mach Numbers From 0 to 1.3. NACA RM A53A13, 1953.

3. Frazer, Alson C., and Anderson, Warren E.: Performance of a Normal-Shock Scoop Inlet With Boundary-Layer Control. NACA RM A53D29, 1953.

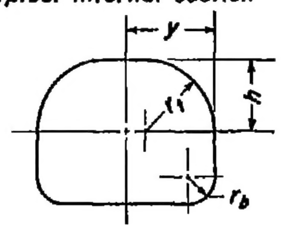
Basic duct dimensions

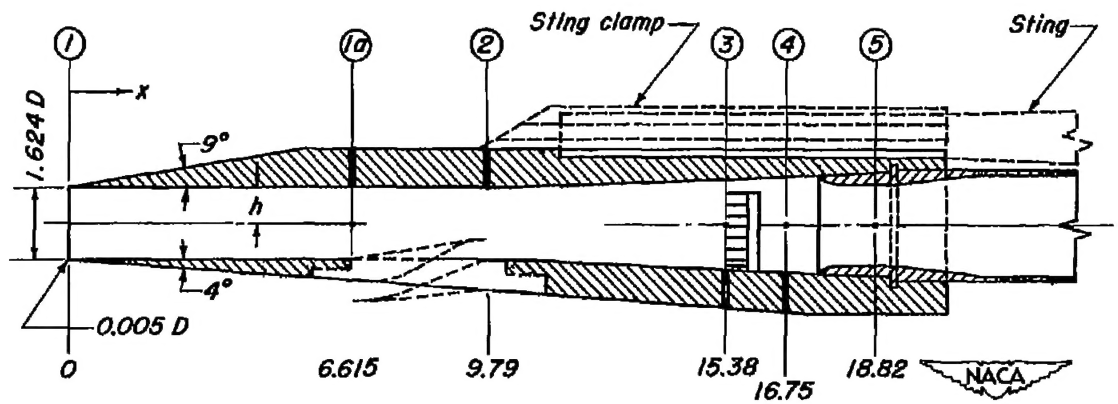
x	y	h	r_t	r_b
0	0.812	0.812	0.812	0.812
1.60	0.816	0.799	↓	0.781
3.20	0.828	0.799	↓	0.722
4.80	0.845	0.800	↓	0.624
6.40	0.915	0.803	↓	0.488
8.00	1.034	0.804	↓	0.312
9.60	1.156	0.805	↓	0.033
10.24	1.197	0.806	↓	0
11.50	↓	0.855	0.855	0.168
13.00	↓	0.921	0.921	0.368
14.50	↓	0.987	0.987	0.568
16.00	↓	1.053	1.053	0.768



All linear dimensions in inches

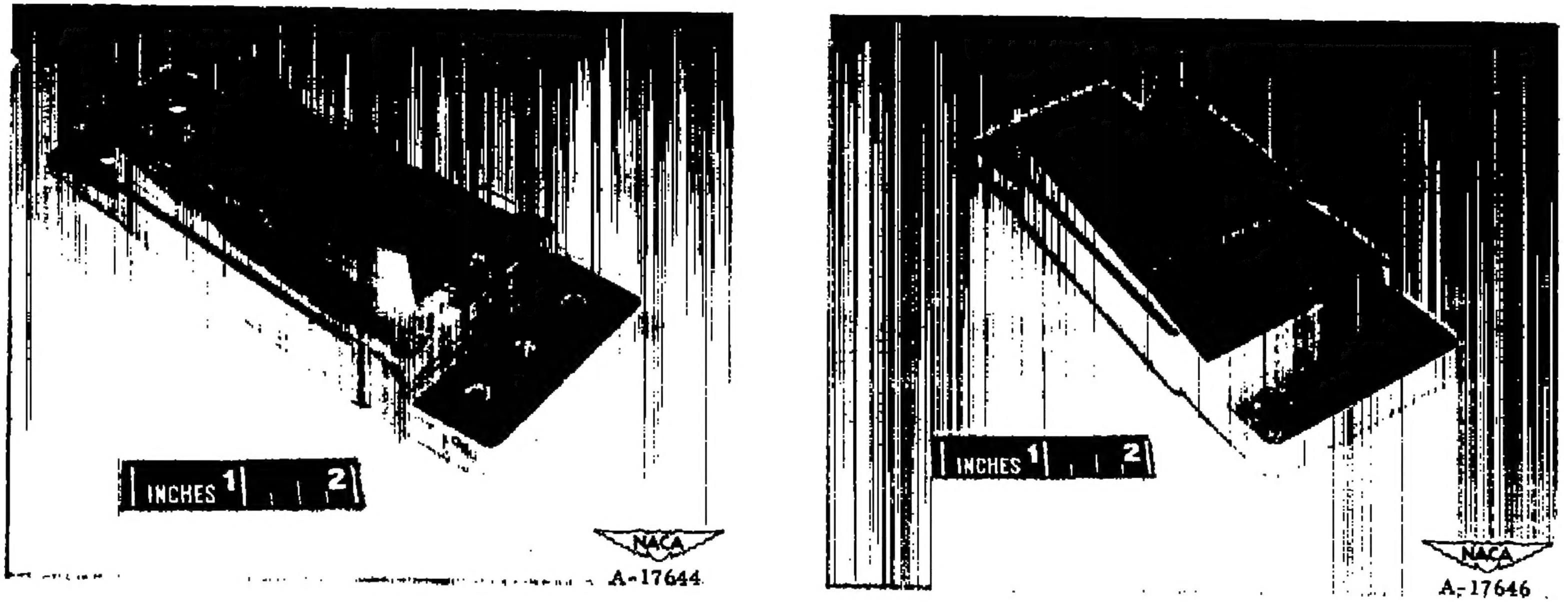
Typical internal section



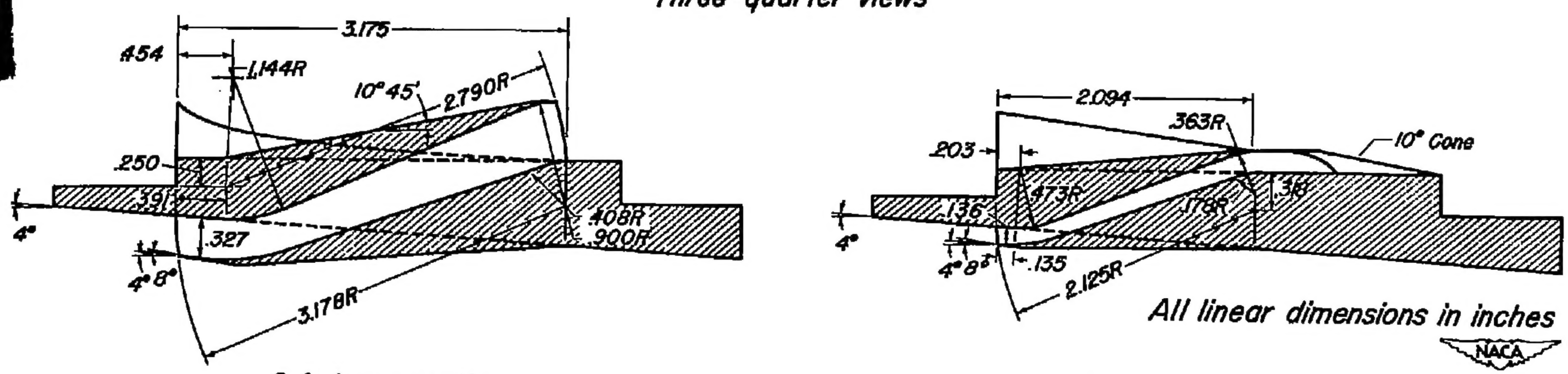


(a) Model with auxiliary inlet.

Figure 1.- Model dimensions.



Three-quarter views



2.4 Aspect ratio

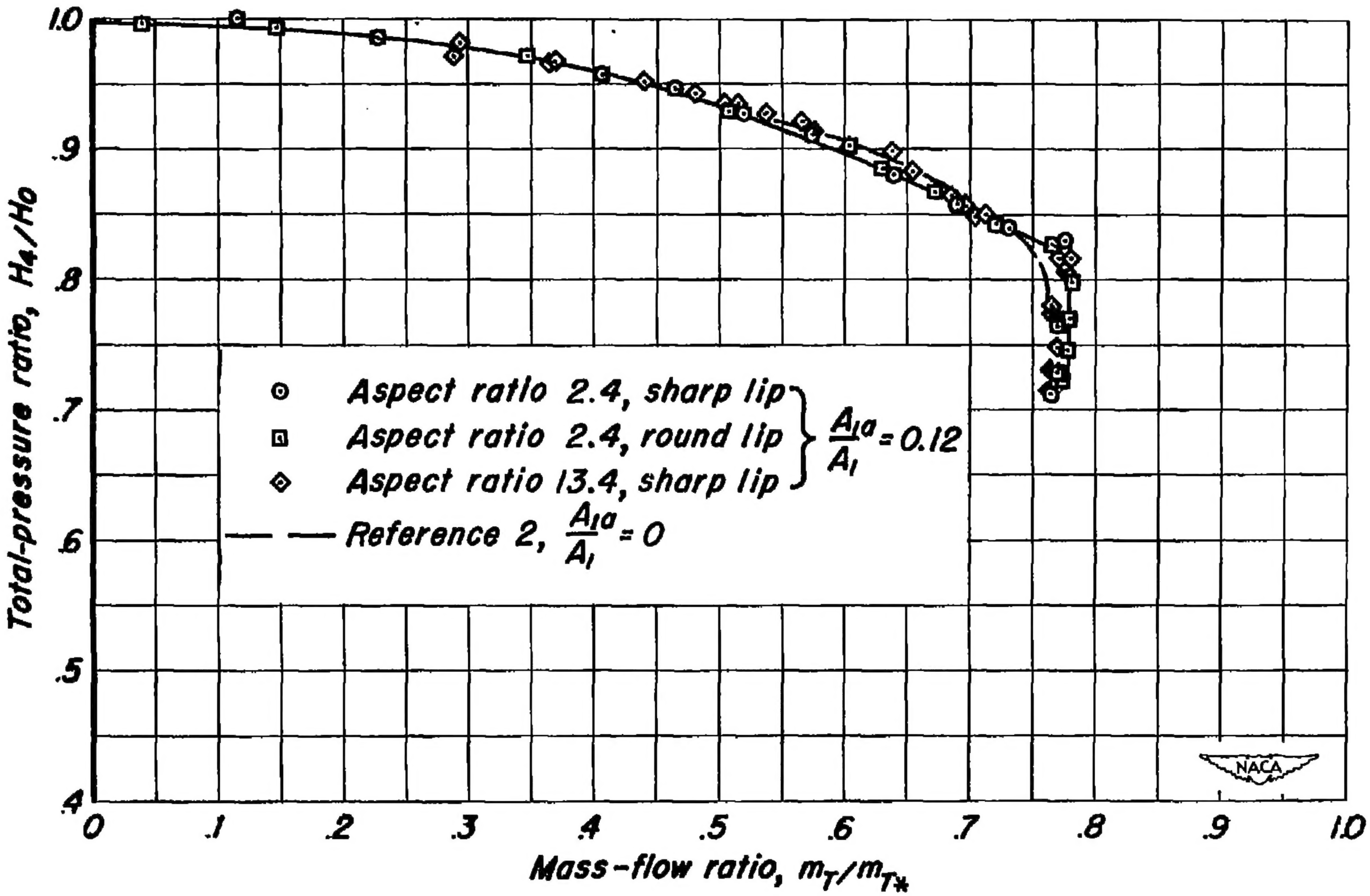
13.4 Aspect ratio

Vertical centerplane sections

(b) Auxiliary inlet details.

Figure 1.- Concluded.

[redacted]



(a) $M_0 = 0$

Figure 2.- Variation of total-pressure recovery with mass flow ratio at zero angle of attack.

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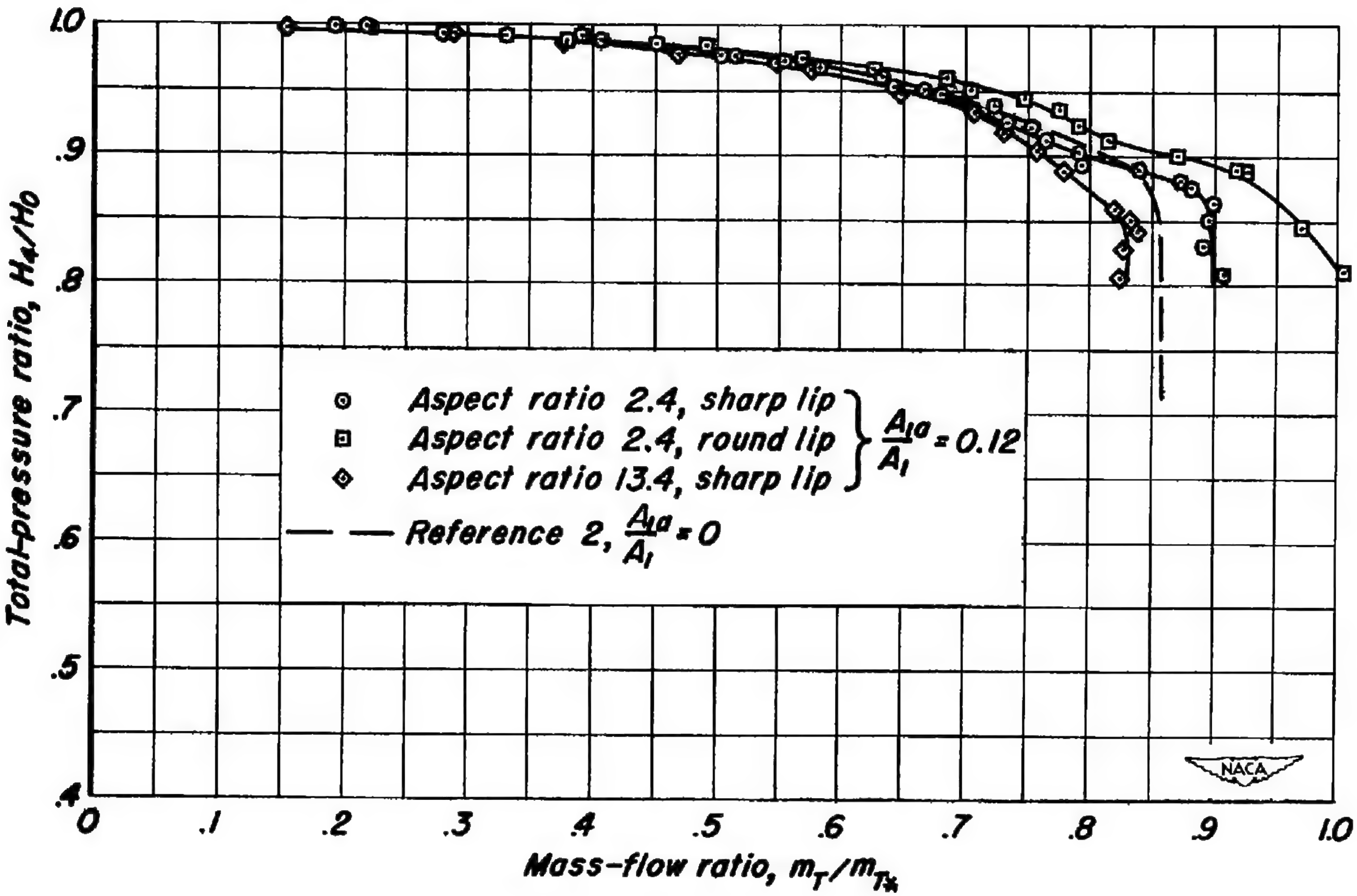
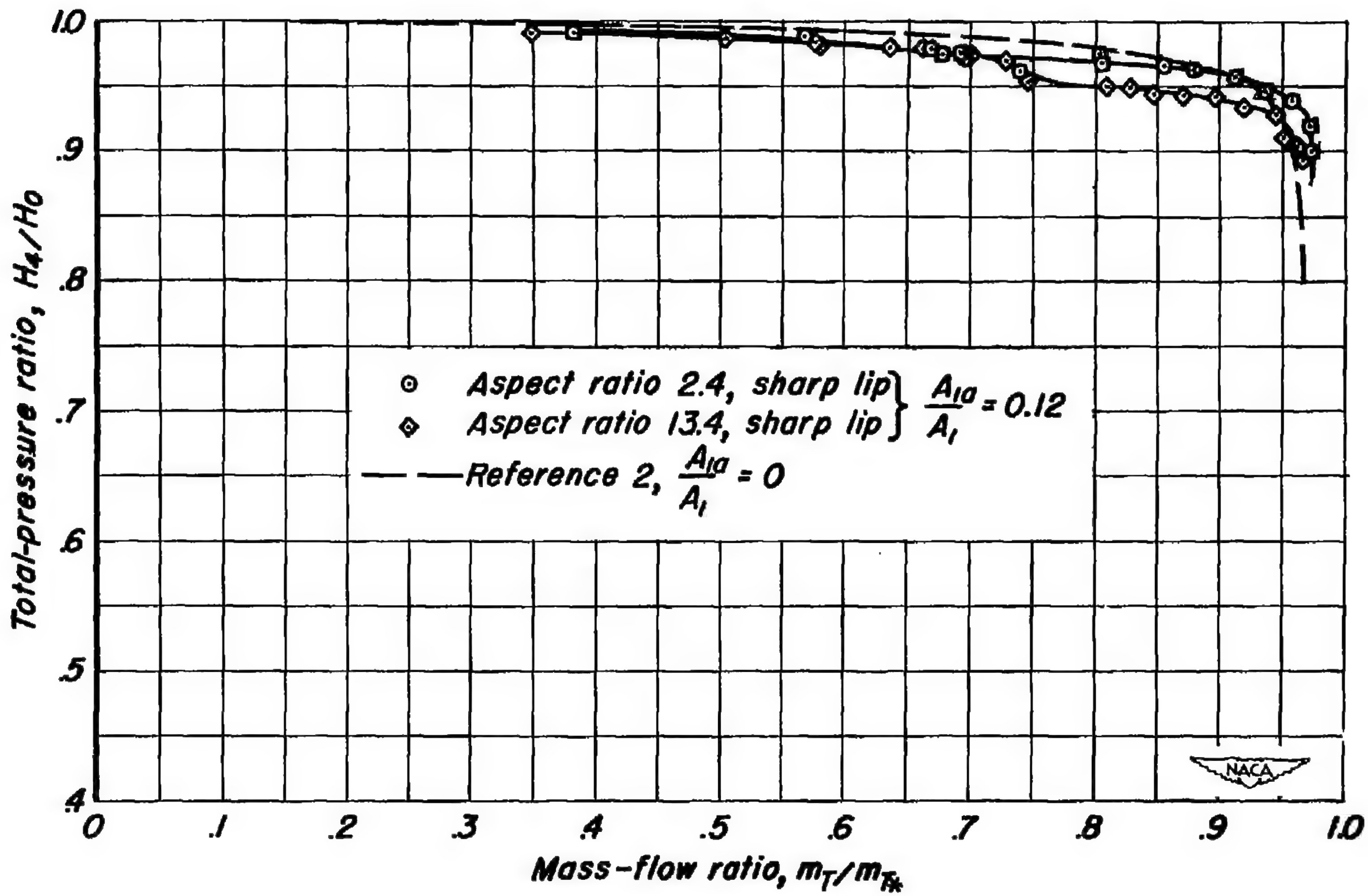


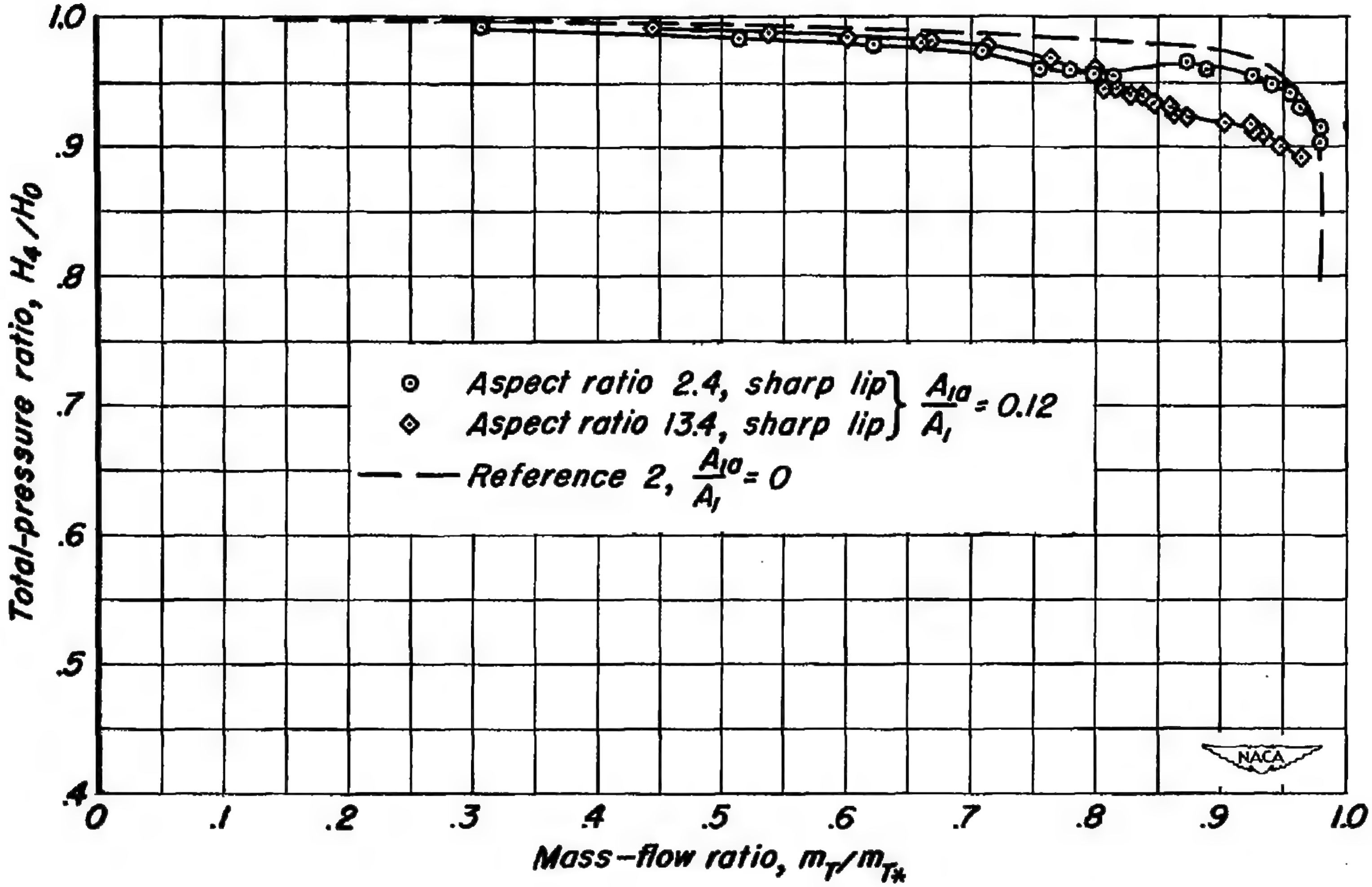
(b) $M_0 = 0.20$

Figure 2.- Continued.



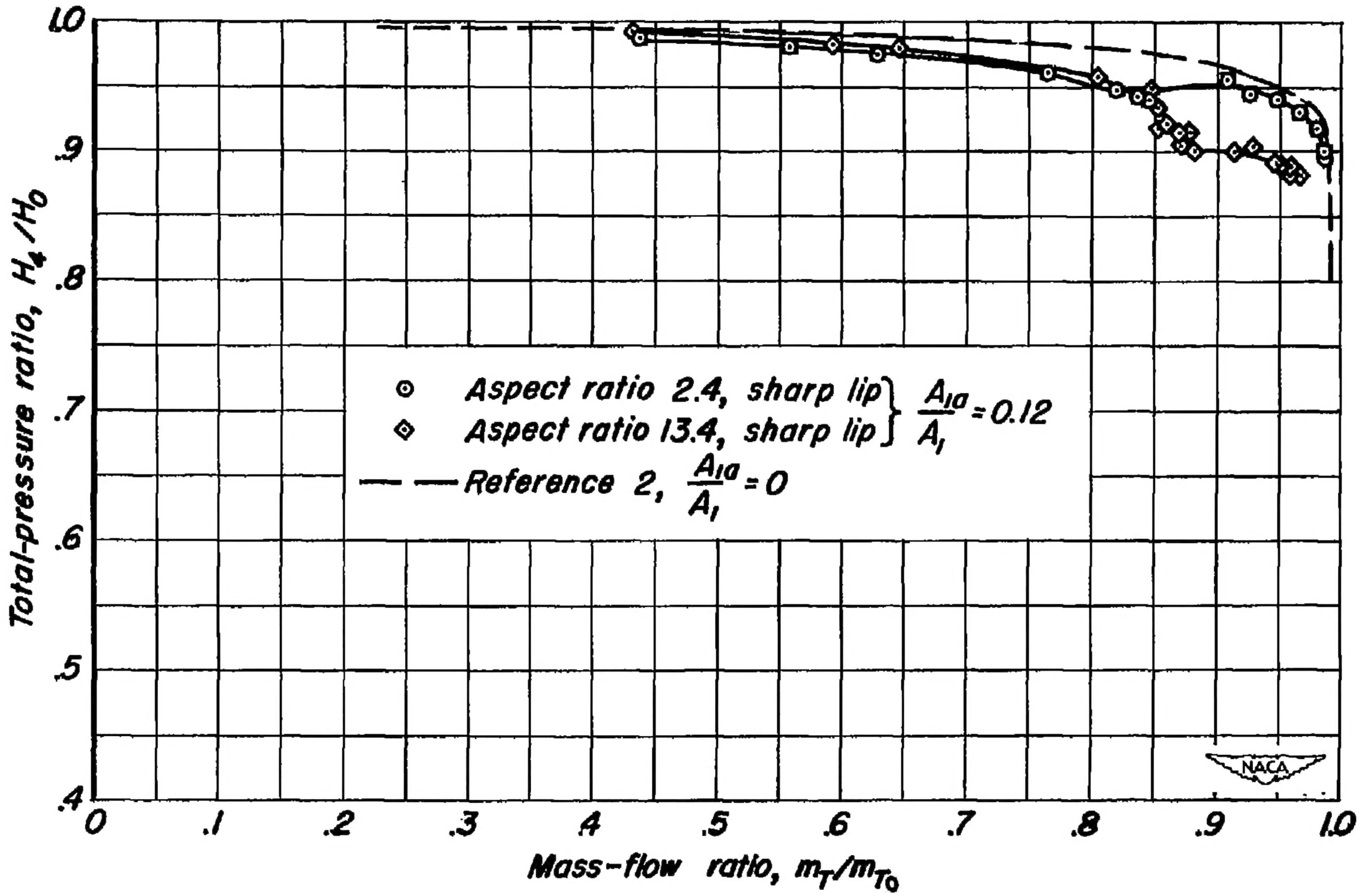
(c) $M_0 = 0.77$

Figure 2.- Continued.



(d) $M_0 = 0.95$

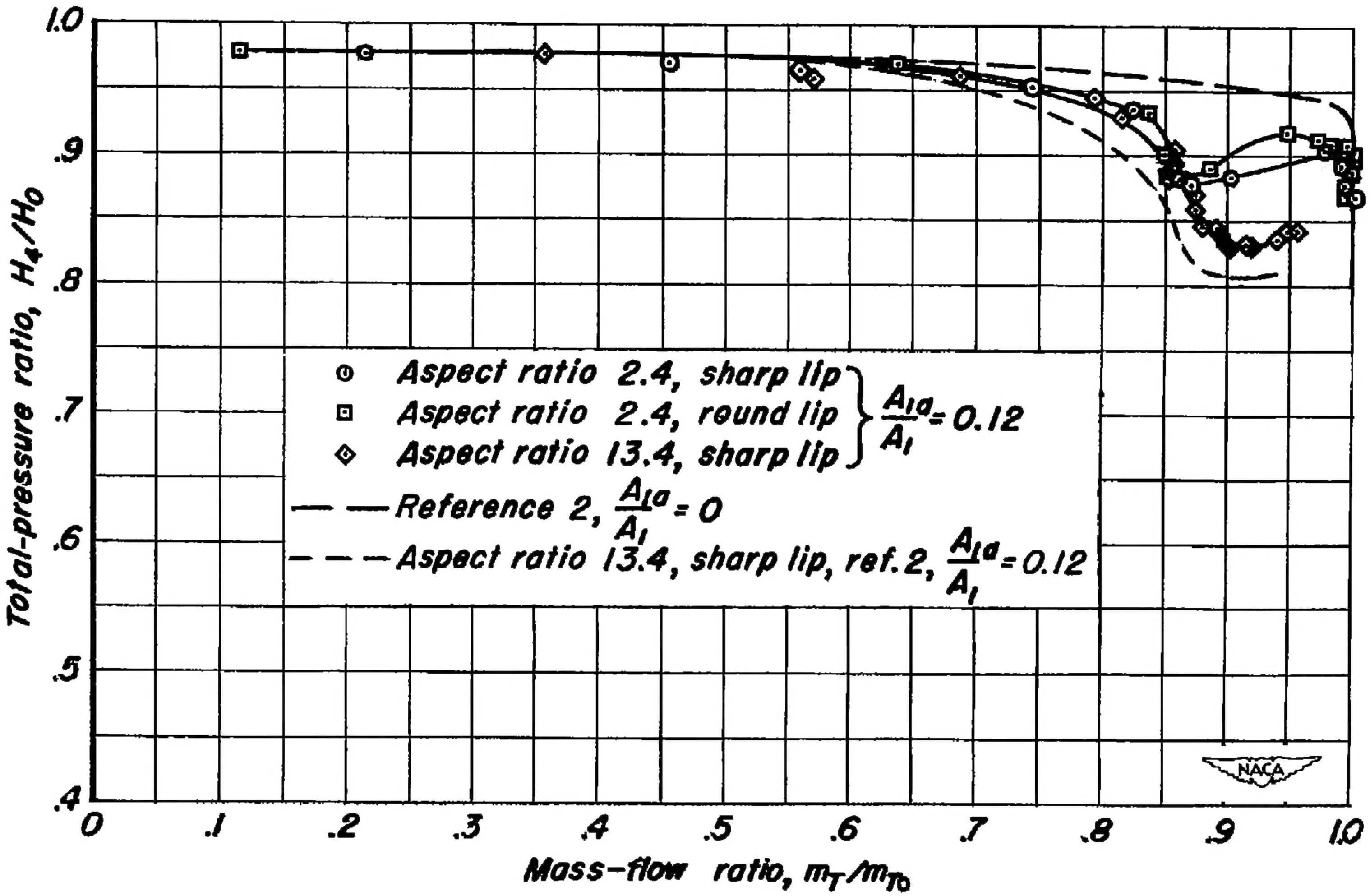
Figure 2.- Continued.



(e) $M_0 = 1.13$

Figure 2.- Continued.

[redacted]



(f) $M_0 = 1.30$

Figure 2.- Concluded.

[redacted]

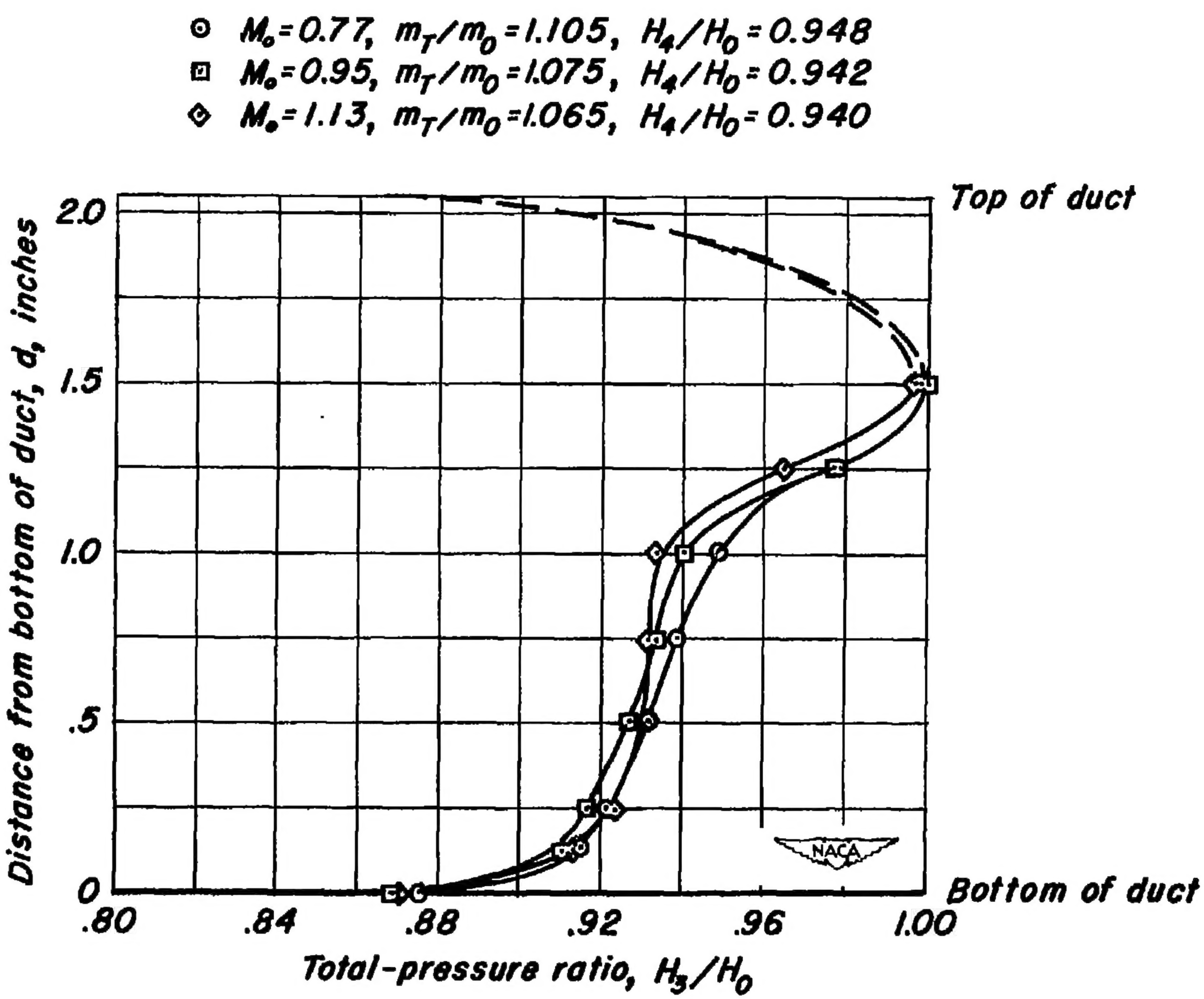


Figure 3.- Total-pressure profiles at station 15.4, for A_{1a}/A_1 = 0.12, 2.4-aspect-ratio auxiliary inlet with sharp lips at 0.77, 0.95, and 1.13 Mach numbers.

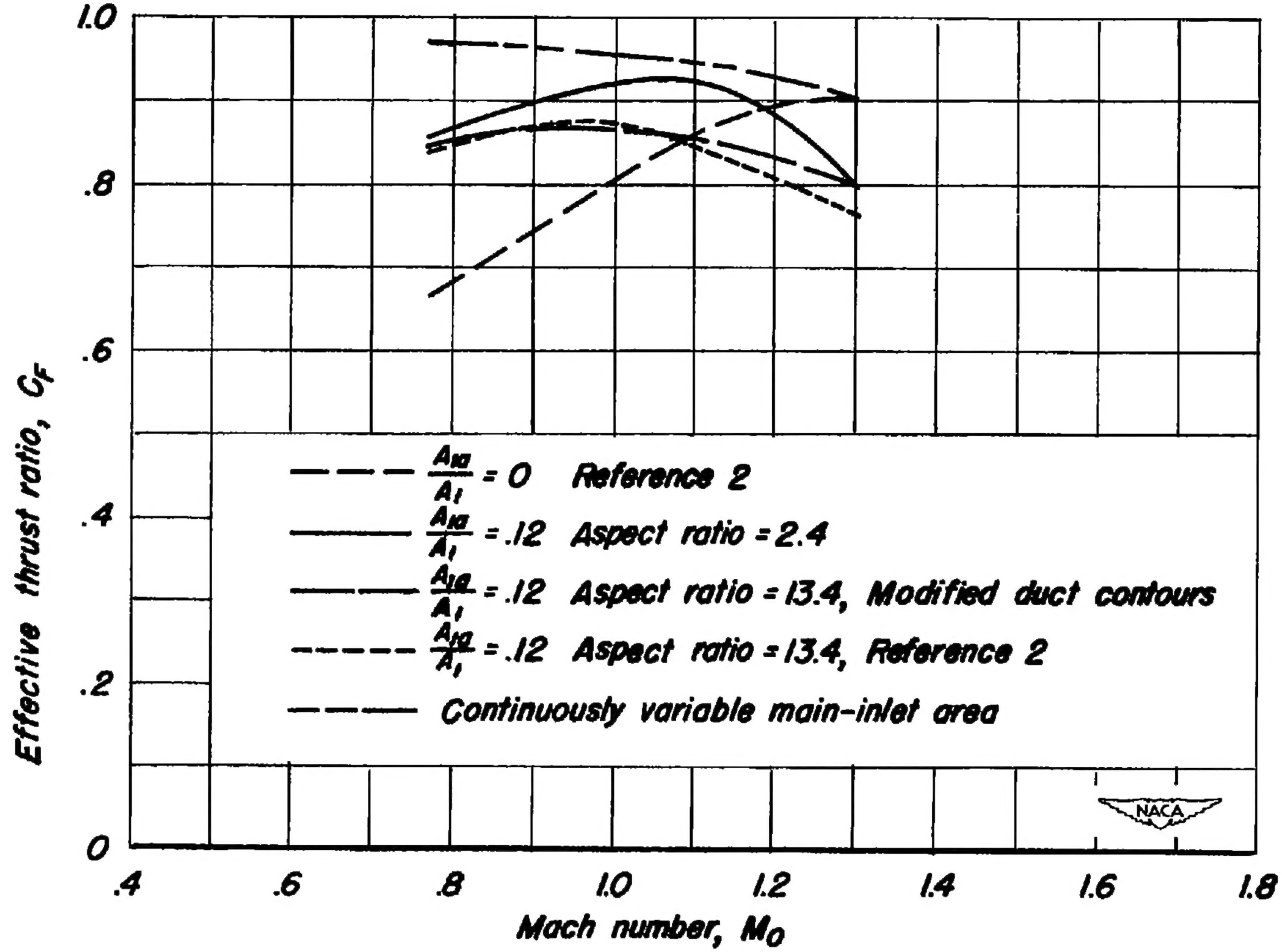


Figure 4.- Variation of effective thrust with Mach number for sharp-lip inlets at 35,000-feet altitude and engine operation at normal rated power.

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